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ADVANCED LIFE SUPPORT SYSTEMS

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BY

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ABSTRACT

Various life support system concepts are analyzed for thermal, atmosphere and water management as well as for food supply in space vehicles. The weight, power and volume requirements are specified for the subsystems considered. An example of a system for a 90 day re-supply, orbiting vehicle with four men aboard is presented. A sodium superoxide system is ~~recommended~~ discussed for short duration systems such as logistic vehicles or stand-by escape vehicles for an orbiting laboratory. The future function of biological systems and the problem of food supply for long duration life support systems is discussed.

ADVANCED LIFE SUPPORT SYSTEMS

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INTRODUCTION

In order to discuss the design of any advanced life support system attention must first be given to the requirements for its use. In any design analysis many new factors not accurately defined must be considered including tentative extrapolations of mission type and profile, boost capability, multiplicity of crews and the availability of technology required to advance the state-of-the-art. These factors are readily evident when we take into consideration the various possible uses of space-life support systems. Man may require a life support system of the portable type for hours or days in one-man extravehicular operations, in orbit, or on the lunar or planetary surfaces. Other short missions may be of the ferry or escape type dictating the need for vehicular life support systems requiring not more than a day of operation and which can be reusable for long periods of time and can be easily re-charged or refurbished in operations remote to the earth or large fixed space installations.

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Advanced life support systems designs may need to consider the factors important in maintaining astronauts in earth orbit for prolonged periods, as in a manned orbiting laboratory or semi-permanent to permanent orbital space stations, temporary or permanent lunar base operations, in the establishment of orbital planetary bases or in the actual establishment of bases on planetary surfaces.

It may be added here that already a need may be arrising for a difference in philosophy between vehicular life support systems for permanent orbital versus exploratory type missions. In the early phases of manned space exploration travel times in vehicles may be for extended periods, however, a projection into the future advances of propulsion may indicate significantly reduced flight times. Stay times in vehicles may well result in matters of months, weeks, and possibly days, rather than several months to a year, or more, as presently envisioned. This implies that some future vehicular life support systems may need be optimized to ground based operations in areas remote to earth and design considerations for long duration vehicular systems may have to include methods for use of lunar or planetary natural resources. This consideration may be required to increase the flexibility of the system and thus permit its use in several varied locations or permit the use of landing vehicles as central processing stations during early phases of base establishment. It is evident, however, that the availability and cost of providing power could be the dominant factor as to whether a lunar or planetary system will be supplied entirely with earth materials or whether some of the natural raw materials could be utilized for life support. Mars may give us some hope for maintenance of the life support systems from existing raw materials although, here too, specific systems design concepts cannot be elucidated until more information is available on the composition and environment of the Mars surface and atmosphere.

There are many approaches to meeting each of the life support requirements of the future and the problem is the selection of the optimum atmosphere, thermal, food, hygiene, water control methods which integrated with the total life support system, the total vehicle system and is consistant with the requirements of each mission phase.

Extensive investigations have been conducted of various methods for meeting life support needs and criteria have been elcuidated which permit the selection of key components for integrated systems for use in missions of up to one (1) year in duration.

In order to access the relative merit of different types of advanced life support system components and subsystems it is imperative that their functions be critically defined.

II. DEFINITION OF LIFE SUPPORT SUBSYSTEMS AND COMPONENTS FUNCTIONS

A. Atmospheric Control

The functions of atmospheric control in the life support system includes pressurization, air circulation, and the supply of gases and removal of contaminants to control air composition in a space system, (suits, cabins, etc.).

Pressurization includes control of the total pressure by means of regulating devices, together with storage and supply of gases to make up losses which may result from leakage and/or decompression.

Air circulation encompasses the transport of air through processing components by means of blowers, ducts, and fittings; and control of the transport by valves, dampers, and diverters.

Air composition control consists of the controlling the composition of air by:

a. Regulating O_2 partial pressure by a continuous or intermittent feed which replaces losses.

b. Regulating CO_2 partial pressure by processing to separate CO_2 from cabin air.

c. Regulating H_2O partial pressure by processing to separate H_2O from cabin air.

d. Processing to remove odors.

e. Removal of contaminant particles.

f. Processing to remove gaseous contaminants to maintain concentrations below maximum allowable.

g. Processing to recover O_2 from CO_2.

B. <u>Thermal Control</u>

Control of temperatures and heat flux in all components except the power source heat rejection is the function of the life support thermal control.

Air temperature control includes processes whereby air is cooled and heated as necessary to maintain cabin air temperature within a specified range. Cooling is required to reject heat absorbed by the air from the crew and equipment and to achieve humidity control. Separation of the humidity condensate is included.

Equipment cooling includes provising the means to cool all heat-producing equipment in the cabin, thereby maintaining equipment temperatures within specified limits.

Heat rejection is defined to mean the total controlled heat flux from the cabin to its surroundings. At equilibrium temperatures, the total heat rejected equals the total heat input to the cabin from all sources.

Heat transport function is the controlled transport of thermal energy from its source to the site of heat rejection. The mechanism of transport may be convective heat transfer from the source to a heat transport fluid (liquid or gaseous) which is pumped to a heat rejection component.

C. <u>Food, Water, and Waste Management</u>

Food management functions include food selection, preserving, storage, preparation for consumption, serving, and zero-g technique of eating. Preservation may be inherent in either a packaging or a storage technique.

Water management includes water storage, testing, dispensing, heating, chilling, and the reclamation of water from wastes.

Waste management includes waste collection, transfer, processing, and storage or disposal. Wastes to be collected include feces; urine; debris from shaving, hair cutting and nail clipping; food wastes; packaging material; vomitus; disposable sanitary supplies; spent filters; carbon and possible other residue from LSS components or from scientific experiments. (Processing of wastes may include disinfecting, decomposing, incinerating, dessicating, or freezing as means of inhibiting bacterial growth.)

D. Controls and Instrumentation

Functions of the controls and instrumentation include sensing and readout of physical quantities such as temperature, pressure, flow, and electrical power, etc.; the means of controlling certain of these quantities in other components and subsystems of the LSS, and alarms to warn of critical malfunction.

III. CONCEPTS OF ADVANCED LIFE SUPPORT COMPONENTS AND SUBSYSTEMS

A. Atmosphere Control

Several storage, partially regenerative, and completely regenerative methods for providing atmospheric gases in advanced life support systems include:

1. Storage of gases as liquids.
2. Generation of oxygen and adsorption of CO_2 by means of stored chemicals.
3. Regeneration of oxygen from waste products.
    a. Electrolysis of water.
    b. Regeneration of oxygen from carbon dioxide by chemical means.
    c. Regeneration of oxygen from carbon dioxide by biological methods.

While pure oxygen may be considered satisfactory for shorter duration missions, extended duration missions may require a mixture of oxygen and nitrogen.

The general categories of atmospheric storage methods are: the high pressure gaseous storage at ambient temperature and cryogenic storage at low (subcritical) or moderate (supercritical) pressures and temperatures.

For certain applications cryogenic stores of atmospheric constituents may be preferred because of their high fluid storage density, and potential as refrigeration and cooling sources.

These advantages are somewhat compromised, but not insurmountably, by various problem areas including adequate thermal insulation to minimize fluid boil-off, control of storage pressure during fluid delivery, adequate storage container venting, controls for rapid repressurization, and fluid quantity determination. Two promising cryogenic storage categories, supercritical and subcritical, are usually divided into two subcategories of fluid expulsion by thermal pressurization and fluid expulsion by a positive mechanical method. For the subcritical storage, delivery of the fluid as a gas, a liquid, or a liquid/gas combination is possible.

Level indication at "zero-g" is difficult with subcritical storage due to the two-phase condition in the tank. Cryogenics may be stored in both the subcritical and subcritical and supercritical states.

The main advantages of subcritical cryogenic storage are low storage weight and volume, ease of resupply and better safety associated with low storage pressures. The d/s advantages of subcritical storage are: complex quantity measuring and high thermal requirements for complete repressurization.

Storage quantity determination is somewhat simpler for supercritical than for subcritical storage since the fluid is homogeneous and the mass of fluid left in the tank is directly proportional to fluid density. The main advantage of the supercritical cryogenic storage is light weight and volume, and elimination of phase separation problems. The main disadvantages include the high thermal input required to transfer fluids to cabins, heavier tank weights than subcritical storage, and resupply is somewhat more difficult and more fluid is lost than for subcritical resupply. Characterisitcs engineering parameters for cryogenic storage of atmospheric gases for periods up to one (1) year are included as table I.

CHARACTERISTIC, CRYOGENIC STORAGE WEIGHT & VOLUME REQUIREMENTS

Table 2

Method Description	Constituent Stored	Storage Pressure PSIA	Weight Penalty W_{tot}/W_u	Volume Penalty V_{tot}/W_u	Comments
Supercritical	Oxygen	1,500	1.555	0.02[illegible]	Al inner shell, Mg outer shell
Subcritical	Oxygen	150	1.140	0.02[illegible]	With vapor delivery, Al inner and Mg outer shell
Supercritical	Nitrogen	1,000	1.258	0.03[illegible]	Ti inner shell, Mg outer shell
Subcritical	Nitrogen	150	1.139	0.03[illegible]	With vapor delivery, Ti inner and Mg outer shell
Supercritical	Air	1,000	1.560	0.04[illegible]	Ti inner shell, Mg outer shell

4. CO_2 Concentration - Oxygen Reclamation

Advanced long duration life support systems will regenerate oxygen from metabolic carbon dioxide. Most physical chemical regeneration systems utilize relatively pure-~~contaminant free~~ carbon dioxide as input. Several atmospheric systems have been investigated for the isolation and concentration of CO_2 from complex atmospheres.

The CO_2 concentration techniques which have received the most consideration are:

1. Molecular Sieve Adsorption
2. Solid Amine Absorption
3. Electrodialysis

Molecular sieve or synthetic zeolite has ~~employed~~ enjoyed the greatest development. In general, the regenerative molecular sieve units utilize a water adsorbent such as silica gel upstream for maximum efficiency. In the event a molecular sieve is "Poisoned" by water it can be desorbed by heating and/or expos~~ed~~ure to vacuum. One area which requires further study is the capability to remove residual cabin air from the voids in sieves prior to the desorption and transfer of CO_2 into an oxygen reclamation system.

Solid amine systems for CO_2 removal consisting of silica gel (approximately 85%), ethylene glycol and solid salts of amino acids have been considered. These systems show promise of being simpler than the molecular sieve system since the same absorber may absorbe both water and CO_2. However, solid amines have achieved only 0.5 to 1% CO_2 capacity by weight at a CO_2 partial pressure of 3.8 mm Hg. The molecular sieve 5A material undersimilar conditions has a capacity of 4 to 6% also, the solid amine exhibits a low temperature requirement for CO_2 desorption to prevent amine decomposition.

Electrodialytic CO_2 scrubbers have the advantage of being continuous and not requiring water removal from the gas stream. In addition to separating CO_2 from the cabin air the units are capable of simultaneously generating O_2 by the electrolysis of water. There are four cells in each compartment containing ion. Present day electroldialysis units incorporating organic anion or cation exchange membranes which must be kept moist at all times. In organic membrane units are being developed which may have higher efficiencies and do not deteriate if allowed to dry out.

A schematic of a typical electrodialytic CO_2 scrubber with oxygen generation (by electrolysis) capability is shown in figure 1.

– CO_2 SCRUBBER

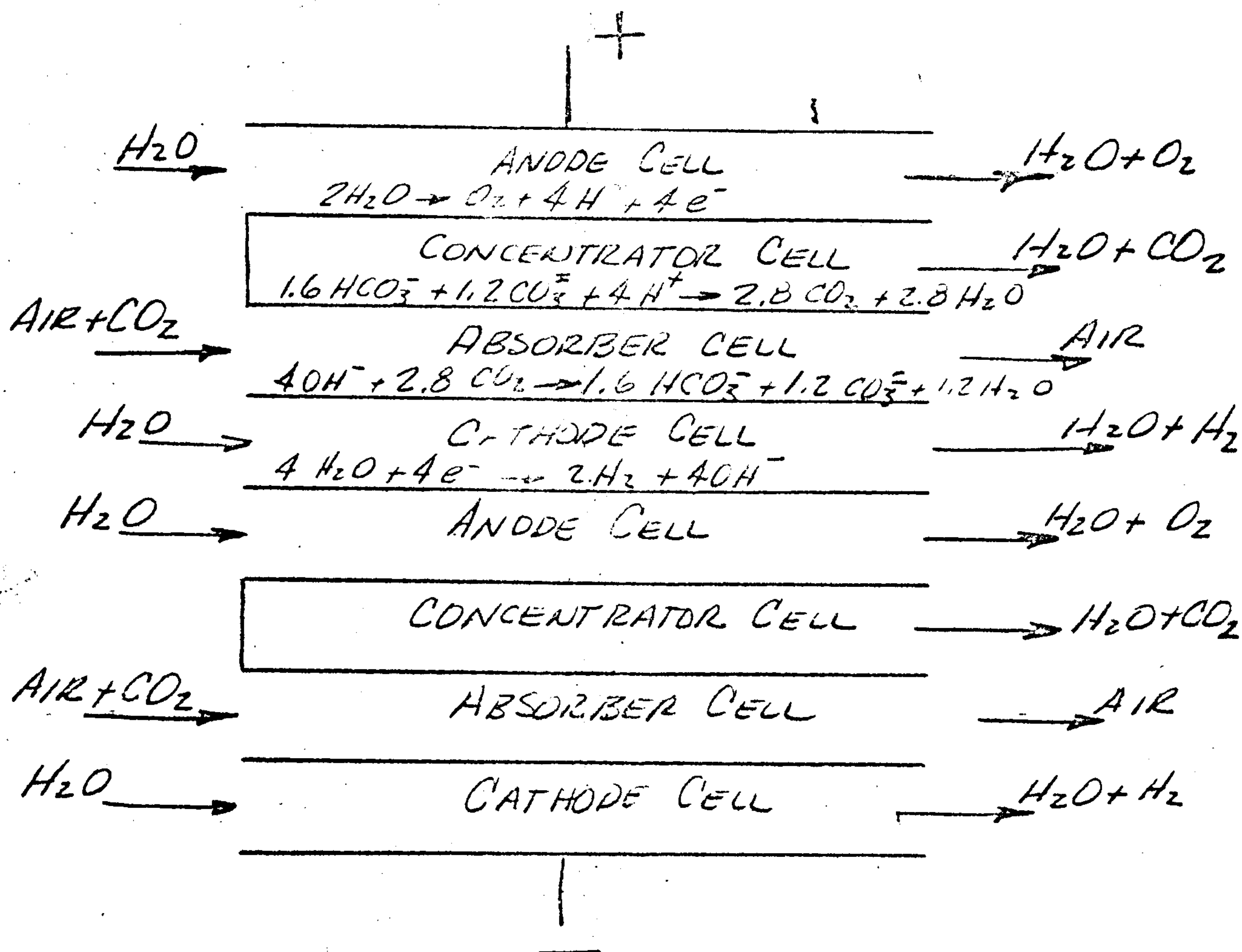


FIG 1

3. CO_2 reduction systems

The physical-chemical oxygen generation systems which have received the most consideration for advanced life support systems are:

1. Bosch Reaction System
2. Sabatier
3. Solid Electrolyte
4. Molten Electrolyte ($LizCO_3$) System

The Bosch reaction system is based on the net reaction:

$$CO_2 + 2H_2 \longrightarrow 2H_2O + C + 921 BTU/lb.\ CO_2\ 1100F$$

Several present day units employ an iron catalyst and operate at temperatures from 800 to 1200°F. (References ?)at 1025°F 30% conversion has been obtained. The reaction has been reported insensitive to pressure variations around one atmosphere. Preliminary experiments have been indicated that upward of 20% N_2 could be tolerated in the reactor loop.

The major problem associated with the Bosch System is carbon removal. One scheme which has been satisfactorily tested consists of the continuous scraping of carbon loose from the catalyst (site of formation) and the transport of scrapings by normal recycle gas flow to regenerable filters. It may be possible to use the porous carbon for cabin air contaminant removal.

The Sabatier systems are based on a reaction which produces methane. Carbon removal is not required if methane is not recovered and is exhausted overboard: (References Nr 1, 2, 3)

$$CO_2 + 4H_2 \text{ --- } CH_4 + 2H_2O$$

The reaction requires catalysts suitable for low temperature operation. Nickel and ruthenium have been used. (Reference 12).

The methane can, however, be recovered by the reaction:

$$CO_2 + CH_4 \text{ --- } 2H_2O + 2C$$

In this process carbon is recovered and essentially the Bosch reaction is accomplished in two steps. This process is under development.

Solid electrolyte systems have been considered which are advantages in that O_2 generation may be controlled by the electrical inputs to an electrolysis cell:

$$2\,CO_2 \xrightarrow[1000°C]{\text{electrolysis}} 2CO + O_2$$

Oxygen in product CO is reclaimed by catalytic chemical reaction. Carbon removal is required. Estimates on carbon to catalyst consumption vary from 10 to 100. At present, the system consumes considerable power and is considered to be in the early stages of development.

Molten electrolyte systems are being considered which have the advantage of being capable of continuous supply of O_2. Inherent problems of these systems include gas transfer in molten electrolytes and the removal of carbon in reduced gravity. In addition H_2 or CO may be formed if the cell is contaminated with water vapor or if the CO_2 and power are not accurately balanced. This system is essentially in the conceptual stage.

Summary of CO_2 Reduction

1. The molten electrolyte and solid electrolyte are in the early stages of development. The Sabatier system with methane decomposition could be made available in a relatively short time. Of the Bosch and Sabatier (no methane recovery) systems the Bosch offers the greatest potential on the basis of overall system weight.
2. The Sabatier system with no methane recovery offers a lighter system than stored oxygen and requires the least development of the physical-chemical systems.
3. The Bosch system shares advantage for oxygen reclamation in advanced life support system for 300 man-days or greater. The Sabatier can be provided as a back-up with little weight penalty. A third alternate mode,

in case of malfunction, would be to simply dump CO_2 overboard during repairs.

Physical characteristics of various O_2 reclamation systems are compared in Table 2.

O_2 RECLAMATION BY CO_2 REDUCTION

(4-man System)

	Sabatier	Bosch	Solid Electrolyte	Molten Electrolyte
State of Development	Advanced	Advanced	Early	Early
Total Weight (Hardware, Power, Heat Rejection)	406 lbs.	531 - 629 lbs.	584 - 1090 lbs.	650 lbs.
Volume	2.2 ft^3	3.3 ft^3	---	---
Expendable Weight	2.37/day to 4.05/day	.75 lb/day	---	---

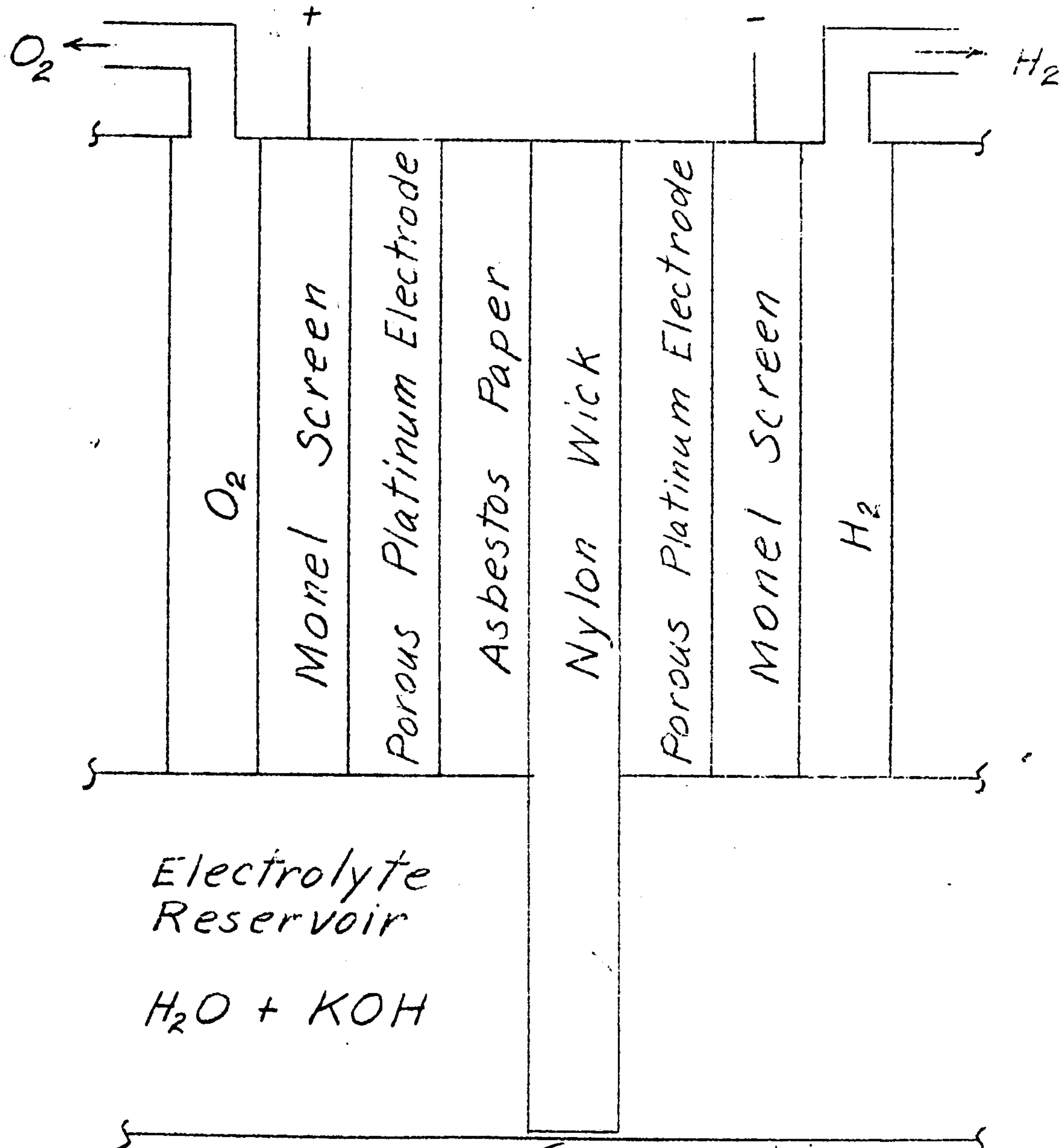
** Does not include storage for H_2.

TABLE 2

4 Zero G Water Electrolysis

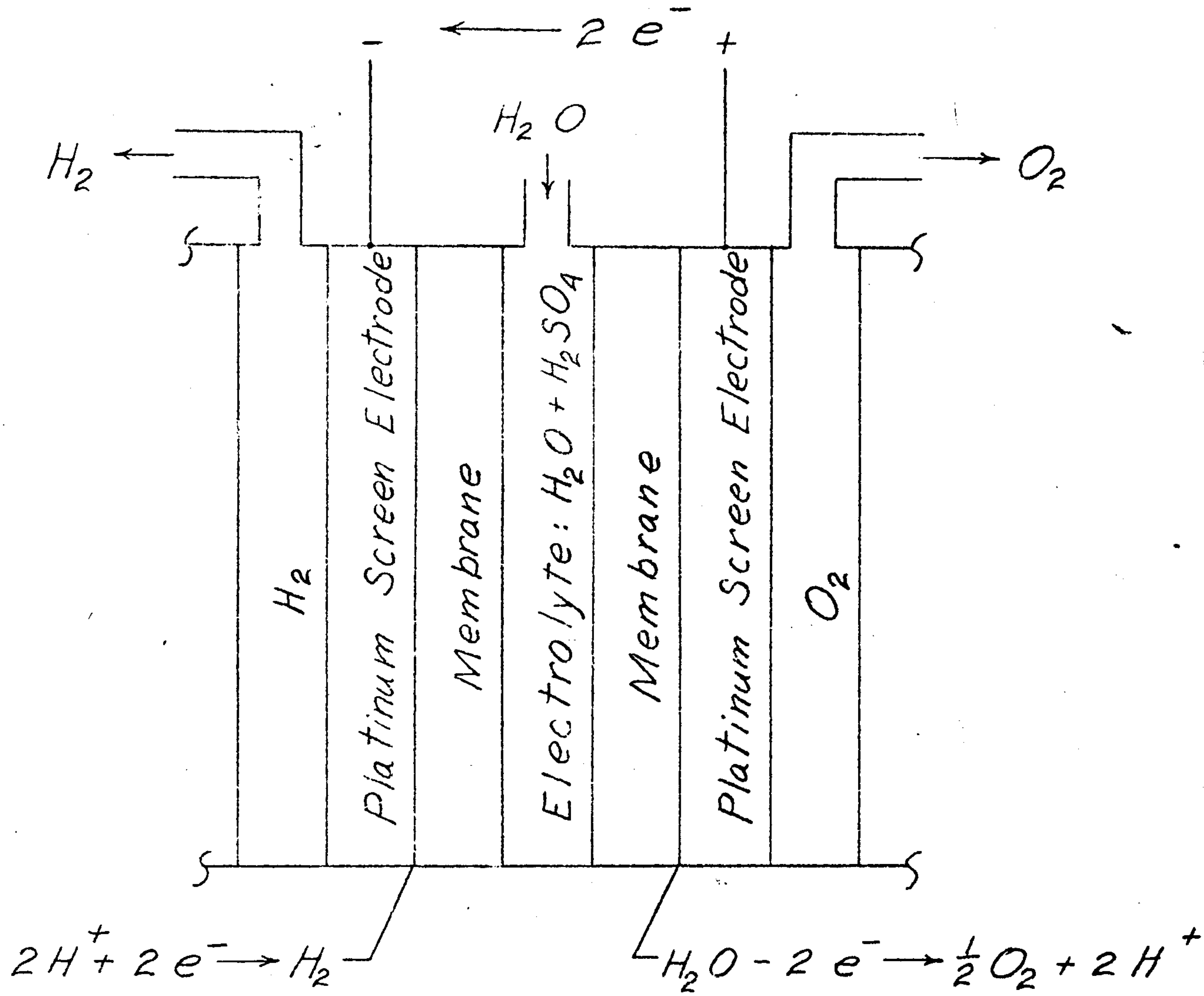
Electrolysis is evolving as an important technique for use in long duration advanced life support systems. Electrolysis units may be used to convert water vapor in the cabin air stream or liquid water from sources including a CO_2 for the reduction of CO_2.

One principal problem area in zero G electrolysis may be the separation of the gaseous products from the liquid electrolyte. If electrolyte is separated away from the electrodes by gas as it evolves, current is interrupted and electrolysis ceases. A worse malfunction would be flooding of electrolyte into the product gases, thereby contaminating the gases with a corrosive liquid. Two approaches to minimizing the problem of reduced gravity are schematically presented as figure 2 and 3 . Several zero gravity electrolite units are either in the laboratory or advanced development stage. The characteristics of several units are presented as table 3 .



O_2
+
-
H_2
O_2
Monel Screen
Porous Platinum Electrode
Asbestos Paper
Nylon Wick
Porous Platinum Electrode
Monel Screen
H_2
Electrolyte Reservoir
H_2O + KOH

Fig 2



$\leftarrow 2e^-$
$-$
$+$
H_2O
H_2
O_2
H_2
Platinum Screen Electrode
Membrane
Electrolyte: $H_2O + H_2SO_4$
Membrane
Platinum Screen Electrode
O_2
$2H^+ + 2e^- \rightarrow H_2$
$H_2O - 2e^- \rightarrow \frac{1}{2}O_2 + 2H^+$

Fig. 3

FORM 73 (REV. 6-61)

TABLE 3-1 WATER ELECTROLYSIS

BASIS: 4 men @ 1.87 lb O_2/man-day = 7.28 lb/day

Weight penalty for power and heat not included.

TYPE	VOL. ft^3	VOLTS	WATTS	ACCESSORIES POUNDS	ACCESSORIES WATTS	WEIGHT HARDWARE		REMARKS
Membrane cell, circulating H_2O, membrane separators	0.92	2.6	1235	12	27	60	3	Accessories include pumps for H_2O coolant flow and liquid gas separators 100^oF.
H_2O Electrolysis	0.54		670			35		
CO_2 Electric Scrubber	1.50		525	12	27	60		
Membrane cells, resin packing			1195	12	27	95	35	
						O_2 Concent		
Double membrane cell circulating H_2SO_4 electrolyte	1.4	1.75	830		45	40	2	150^oF operating temperature.
Nylon wick in KOH solution Asbestos liquid-vapor separator	0.1	1.9	912			24		Probably about 20 watts should be added for coolant pump.
Rotating. NaOH Solution.	1.9	28	840		100	141		170^oF H_2 and O_2 assumed saturated with H_2O vapor.
P_2O_5 matrix, air dehumidifier with acid electrolysis	1.2	28	1540			141 LESS De		120^oF. More power required for air flow.
Palladium Cathode hydrogen diffusion	0.3		700	3 Vaporizer	140	50		Need 10-16 months development time.
P_2O_5, similar to #6	2.8		1680			122 LESS D		More power required for air flow.
KOH, circulating electrolyte cyclone separators. 18 cells.		28	76[illegible]		50	100		

Table 3
pp. 25

5. <u>Trace Contaminants</u>

The anticipated contaminants aboard a spacecraft are the subject of much recent literature. The survey of possible contaminants that may be expected in the atmosphere of a spacecraft on an extended flight indicate that they will be numerous and varying in concentration. Extensive lists of contaminants from nuclear submarines, spacecraft simulators and actual mercury space flights illustrate the wide range of contaminants which may be expected.

There is an abundance of information available on industrial toxicity problems which report threshold limit values (TLV) for numerous substances. The industrial data cannot be applied directly to the space environment since this data is for 40 hours per week exposure whereasthe spacecraft exposure will be continuous at 168 hours per week. As a starting point, the acceptable level of these contaminants expected may be arbitrarily set as space maximum acceptable concentrations by reducing the industrial TLV by a factor of 10. However, a great need exists for research to establish maximum levels of contamination for continuous exposure to specific contaminants.

B. FOOD, WATER, AND WASTE MANAGEMENT

In advanced life support systems water management must include means for the collection, storage, reclamation analysis, and dispensing of water. Water may be processed from urine, cabin condensate, feces and that used for personal hygiene. The problem is to process water in the zero gravity environment which is free from dissolved impurities, harmful micro-organisms and disagreeable organoleptic characteristics.

Urine contains about 4.7% total solids by weight. A rough breakdown of these solids is as follows:

Urea	50%
Inorganic salts (mostly NaCl & KCl)	28%
Other organics	22%

Several urine purification techniques have the demonstrated capability to reclaim potable water of a quality equal to that based on present day standards for municipal water supplies. These techniques include:

1. Electrodialysis Adsorption

The recovery of potable water from urine by this process involves three basic steps, namely the precipitation of urea with a complexing agent, adsorption by activated charcoal for removal of additional organic constituents (including those causing odor and color) and demineralization which is accomplished by electrodialysis. Disadvantages noted for electrodialysis adsorption include: large quantities of activated charcoal are required for organic constituent removal, relatively low recovery efficiency (because of water lost in activated carbon) and relative complexity compared to other systems.

2. Vacuum Distillation - Pyrolysis

Vacuum distillation involves a low temperature, low pressure vaporization of water from urine. Breakdown of urea and other organics is thus minimized; nevertheless, the water recovered by condensing vapor is not of good quality and may contain dissolved ammonia, and volatile organics carried over in the distillation. In many cases the distillate must be further treated before the product is considered potable. Pyrolysis (a high temperature catalytic oxidation) is one effective means of eliminating offensive constituents from distilled urine.

Expendable weights are low but it has the highest power requirement of systems considered.

3. Vapor Compression - Adsorption

Vapor compression (compression distillation) is a distillation process that conserves the latent heat of vaporization of the feed. The heat transfer from the condensing vapor is accomplished by compressing the vapor so that it condenses at a higher pressure and thus, higher temperature. The maximum temperature of vapor in this process is about 100° F and the extent of breakdown of urea and other organics is low. Condensate from this process must be further treated to render it potable.

4. Waste Heat Air Evaporation - Adsorption

Waste heat evaporation processes, in general, make use of metabolic heat and waste heat to provide the latent heat of vaporization. Several units use wicks for urine water evaporation. Metering of urine to wicks at rates sufficient for maintaining wicks saturated without flooding the evaporator has presented somewhat of a problem in the past.

5. Waste Heat Vacuum Distillation - Adsorption

The waste heat evaporation process is relatively simple. It employs a rotating evaporator and condenser. The condensate is usually treated with activated carbon and ion exchange resin for final purification.

Used wash water is a significantly less contaminated waste water than urine, and all the systems described for urine water reclamation are applicable to wash water recovery. The total amount of soluable solids removed by bathing has been found to be approximately 1-g gram? per bathing (Reference ?). Addition of 500 ? ppm of disinfectant cleansing agent brings the soluable solids concentration up to 0.09% for 5 lbs. of wash water. Insoluable solids 1(hair, skin, grit, fats) amount to another 1.8 g or approximately .08%. The total solids concentration for 5 lbs. of wash water is thus about .17%.

not clear

The dissolved substances in wash water are, of course, those substances secreted through the skin in sweat. A rough breakdown of the chemical composition of sweat (excluding water) is as follows:

Chlorides (mostly sodium)	40%
Urea	11%
Sebum (fats & Oils)	18%
Lactic acid	8%
Various other substances (mostly organic)	23%

Power and hardware weights will generally be higher for wash water reclamation since a greater quantity of water must be processed. Expendible weights, on the other hand, will be lower since the concentration of dissolved substances in wash water is much lower than it is in urine (by a factor of 50 for 5 lbs of wash water assuming the use of 500 ppm of cleansing agent.

One system not considered in the reclamation of urine water (because of its high weight) is the multi-filtration system consisting of a filter, activated charcoal bed and ion exchange resin bed in series. The lower concentration of solids in wash water does, however, make this system applicable to reclamation of wash water. The humidity condensate is another source of water in the closed cabin. The contamination level of humidity condensate depends on many considerations which include:

1. Type of system used for oxygen supply and CO_2 removal.
2. Auxiliary equipment used for removal of trace contaminants in the cabin atmosphere (e.g., a catalytic burner).
3. Materials of construction used for the condensate coils.
4. Nature of paints, coatings, insulation, etc., used to operate cabin equipment.
5. Nature of lubricants, greases or other substances used to operate cabin equipment.
6. Degree of contamination of cabin air from other subsystems, e.g., feces collection and storage subsystem.

A survey of literature pertaining to submarine and space simulator dehumidification water was made ~~by Steele, et al, Reference ____~~. It was concluded in this study that cabin dehumidification water "will be potable except for the possible presence of pathogenic micro-organisms and a slight odor." It was concluded also that the maximum impurity level of the condensate water would be as follows:

Total solids	70 ppm
Total particulate matter	25 ppm
Total dissolved solids	45 ppm (approx. 1/2 organic and 1/2 inorganic)

Recovery of potable water from humidity condensate has been demonstrated by multi-filtration using activated carbon and a bacteria filter. Proper cleansing of the filters and activated carbon before use is of great importance in order to achieve satisfactory operation.

Also, the ultraviolet light has been demonstrated as an excellent means of killing both bacteria and virus in water reclamation systems. The characteristics of various water reclamation systems are included as Table 4 and presented as a function of time in figure 4. Values presented are based on the assumption of a 4 man crew and an assumed power penalty of 290 #/KW.

FORM 73 (REV 6-61).

TABLE 8.1 PHYSICAL CHARACTERISTICS OF 4 Man URINE RECOVERY SYSTEMS[1]

SYSTEM	VOLUME Ft^3	POWER Watts	HEAT REJECTION Btu/Hr.	WEIGHT: Weight HARDWARE	WEIGHT: POWER PENALTY	WEIGHT: HEAT REJECTION PENALTY	WEIGHT: EXPENDABLE WEIGHT	REMARKS
1) Electrodialysis - Adsorption	4.1	51		16.7			107.0	Pumps assumed to be 50% efficient. Pumps available now about 3-5% efficient. Weight could be reduced appreciably ;if charcoal could be regenerated.
2) Vacuum Distillation - Pyrolysis (Electrical Energy)	1.5	376	1265	24			14.4	
3) Vapor Compression - Adsorption	2.[illegible]	55	Negligible	35			28.6	Expendable weight and water carried for efficiency less than 95% might be higher than required since carbon and resin not used to exhaustion.
4) Waste Heat Air Evaporation Adsorption	6.[illegible]	40	~~Note 2~~	35.4			55.0	Expendable weights determined experimentally. Reported recovery efficiency seems unrealistically high. No penalty applied for water lost in carbon although it probably should be (estimated at 10 lbs).
5) Waste Heat Vacuum - Distillation - Adsorption	2.5	30	~~Note 2~~	40			36.7	Weight shown for expendables and as water to make up for inefficiency may be higher than required.
6) Waste Heat Vacuum - Distillation - Pyrolysis	1.5	98	284	15			14.4	Hardware weight believed to be higher than estimated shown (by approximately 10 lbs).

NOTES: 1) Basis: 4 men at 4.13 lbs/man day = 16.5 lbs/day; 90 days; recovery rate = 1.03 lbs/h
2)

Table A
pp 34

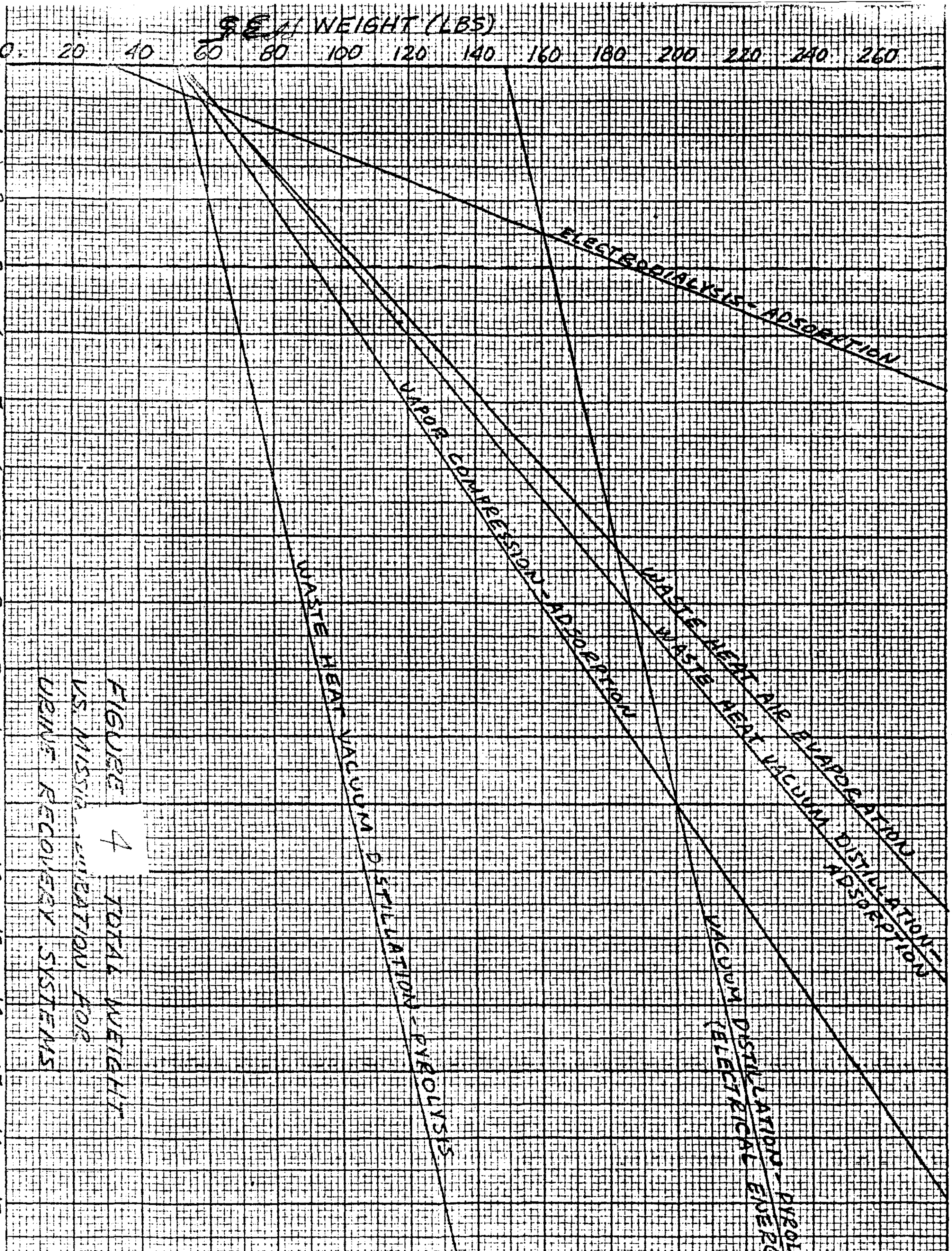


FIGURE 4 TOTAL WEIGHT VS MISSION DURATION FOR URINE RECOVERY SYSTEMS

6. **Food**

The development of agriculture about 9000 years ago permitted an enormous increase in the world population. Since then, the chemist has produced from non-living materials almost all of the substances essential to human nutrition. Based on this progress it has been predicted that the chemist can make as great a contribution to civilization in the next century as agriculture did 9000 years ago. The space program will require such accomplishments sooner than "the next century" of course. It also imposes an additional requirement that the food should be capable of regeneration. Condensing this latter point, the development of a closed ecology appears feasible by the use of a biological system. Higher plants, algae, and bacteria systems have been investigated. For the immediate future the use of freeze-dried foods, without regeneration, appears probable.

Freeze-dried foods are reconstituted by adding hot, room temperature or chilled water to the food package which is then eaten without further processing other than mixing. The food or beverage is ingested by squeezing the contents through a self-sealing mouthpiece into the mouth. It is desired that freeze-dried products be formulated so that all foods to be consumed together would rehydrate in about the same time. The foods should be capable of rehydration in as short a time as possible without sacrificing quality. Maximum time of rehydration should be less than ten minutes.

Freeze-dried and "dried" food weights:

Weight of food is approximately 1.35 lbs/man day. Moisture in individual food items would range from 2% for freeze dry food to 20-24% for dates, figs, dried apricots and peaches. This is equivalent to 1.25 lb or 567 g of food on a moisture-free basis. About 1% of moisture-free food consists, of vitamins, color, odor, and flavor ingredients of no caloric value (5.67 g). About 2% consists of crude fiber of no caloric value (11.34 g). About 5% consists of minerals of no caloric value (28.35 g). About 5% is set aside as a safety factor, some of this would be waste (28.35 g).

Total weight of noncaloric portion of food (73.71 g) is subtracted from moisture-free food (567 g) which leaves 493 g as the caloric portion of dry food/man/day. Figuring on the basis of 25% fat in the diet, this would equal about 2490 calories, and since the digestibility of the ration would also be a factor, we would assume a net theoretical caloric value of about 2300 calories from dry food.

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In lieu of yellow

value (11.34 g). About 5% consists of minerals of no caloric value (28.35 g). About 5% is set aside as a safety factor, some of this would be waste (28.35 g).

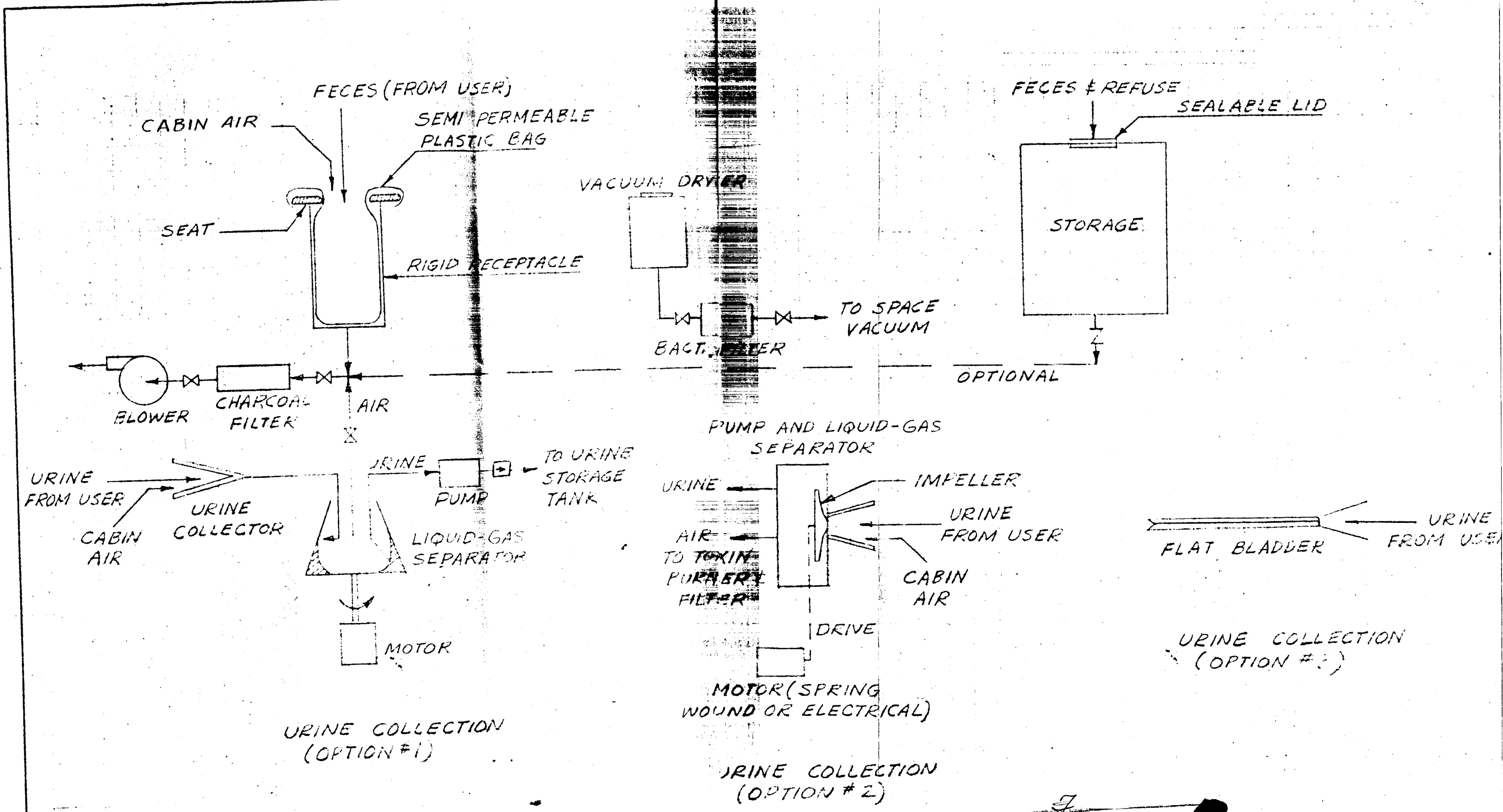
Total weight of noncaloric portion of food (73.71 g) is subtracted from moisture-free food (567 g) which leaves 493 g as the caloric portion of dry food/man/day. Figuring on the basis of 25% fat in the diet, this would equal about 2490 calories, and since the digestibility of the ration would also be a factor, we would assume a net theoretical caloric value of about 2300 calories from dry food.

7. <u>Waste Management</u>

A significant problem area in long duration multi-manned space systems is the handling of waste materials. One approach is shown as figure 5 .

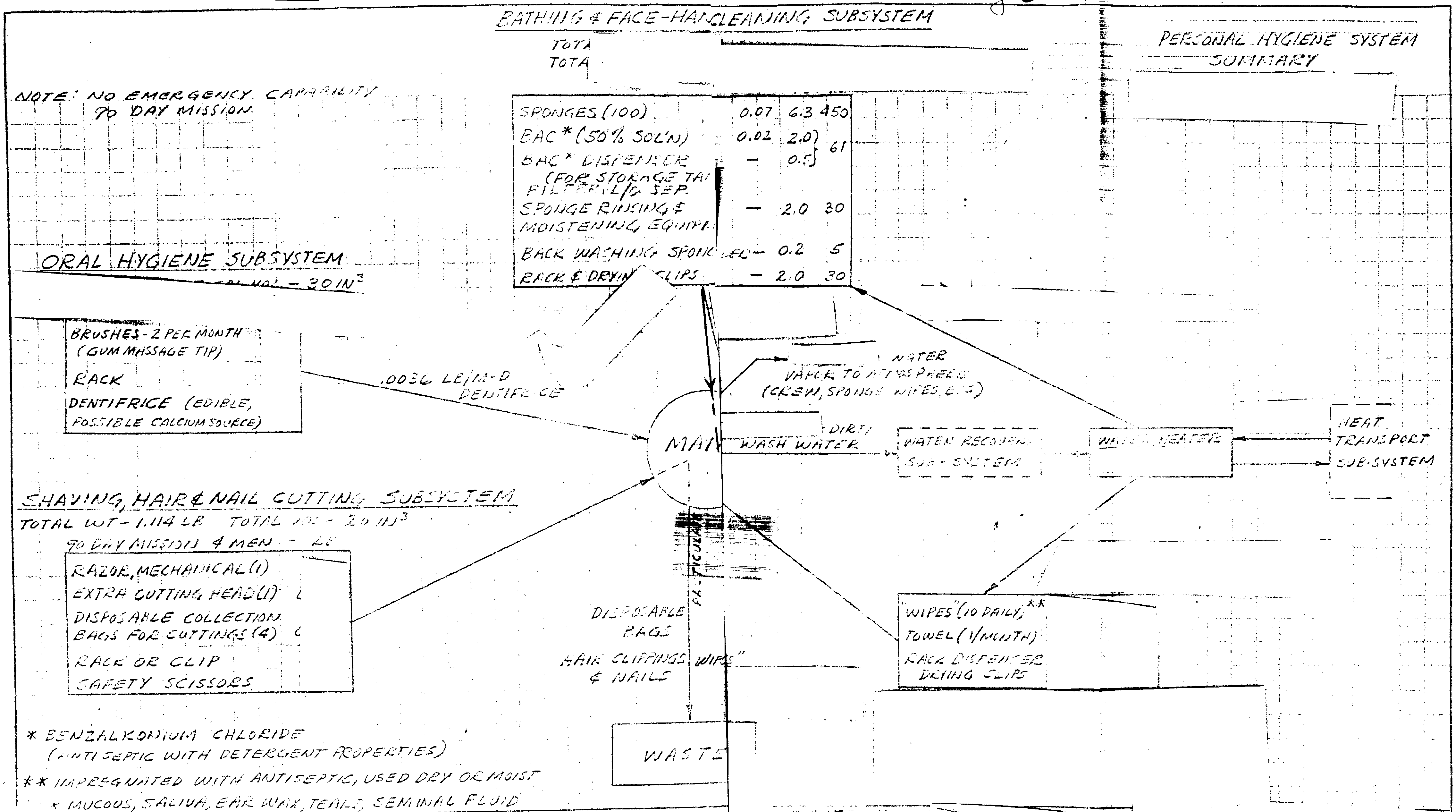
8. <u>Personal Hygiene</u>

Personal cleanliness and the removal of hair and nails from the body require a large number of devices and appurtenances as shown in figure 6 .



WASTE MANAGEMENT SCHEMATIC

Fig. 6



PERSONAL HYGIENE SYSTEM SCHEMATIC

PP. 40

IV. INTEGRATED LIFE SUPPORT SYSTEMS

A. Adaptability of Components and Subsystems

The adaptability of the components and subsystems of life support system, to be integrated with other spacecraft systems, is of significant importance and can be a major factor in the selection of a given functional life support system technique. In order to perform a rational analysis and design of a prototype life support system, the details of system integration must be stressed. To achieve economical, efficient and coordinated design of the various subsystems, the following must be considered:

1. Maximum utilization of the byproducts of the life support subsystems and the spacecraft systems.
2. Compatibility of weight, power, volume and performance of the life support system with the spacecraft requirements.
3. Design and performance compatibility of the subsystems.
4. Integration of subsystem interfaces.

5. Potentially High Integration Considerations

   a. Power Supply and Power Constraints

   b. Waste Heat Availability

   c. LSS Heat Loads

   d. Spacecraft Wall Thermal Characteristics

   e. Mission Parameters and Spacecraft Orientation

   f. Spacecraft Configuration

   g. Resupply Techniques

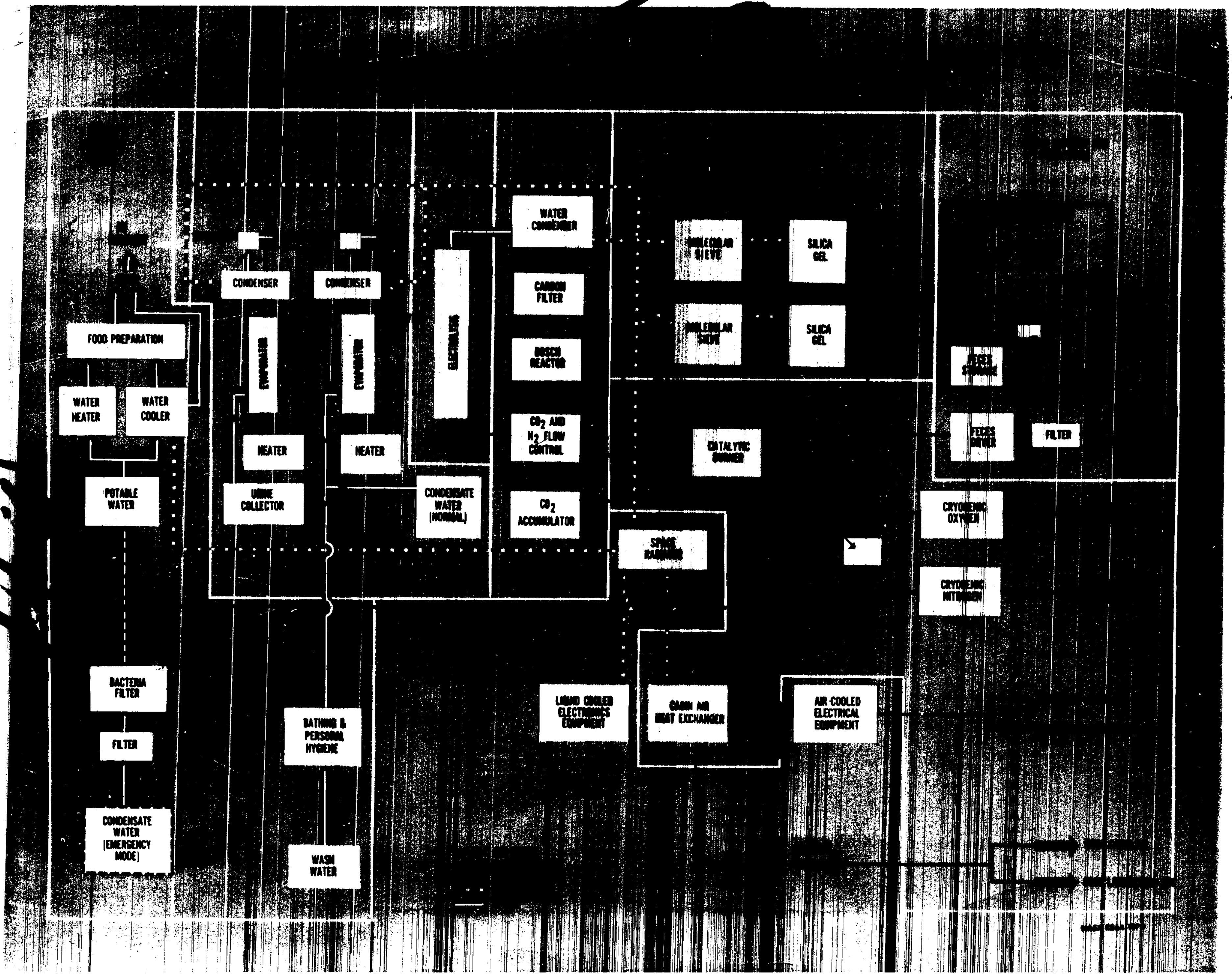
   h. Crew Safety and Emergency Procedures

In studies to date the integration aspects of life support systems show that the thermal control system must be as the principle matrix which ties all of the life support subsystems together. The thermal control system plays an important role in the internal life support system integration, but integrates functionally with spacecraft concepts and other subsystems.

V. From the discussion of the above concepts various advanced life support systems may be conceived. One advanced system for multi-manned crews on extended duration space missions of up to one (1) year could be as shown in figure 16. The components selected are as shown in the figure. Though not illustrated, an alternate mode Sabatier CO_2 reduction system would be provided. A second alternate would be to dump the CO_2 to space in case of failure of both the Bosch and Sabatier systems.

The urine is processed and used for wash water which is then processed and used for potable drinking water. An alternate or emergency mode is to use the condensate water from the cabin air heat exchanger as potable water after filtering.

For systems to be available in the next ten or fifteen years it has been conjectured that increase of distance and increase in duration of transit time were synomous. If this assumption is not borne out due to advances in propulsion systems, then there will be an increased emphasis on long duration systems for operation on planetary bodies. Biological space vehicles due to space


FOOD PREPARATION
WATER HEATER
WATER COOLER
POTABLE WATER
BACTERIA FILTER
FILTER
CONDENSATE WATER (EMERGENCY MODE)
CONDENSER
CONDENSER
EVAPORATOR
EVAPORATOR
HEATER
HEATER
URINE COLLECTOR
CONDENSATE WATER (NORMAL)
BATHING & PERSONAL HYGIENE
WASH WATER
ELECTROLYSIS
WATER CONDENSER
CARBON FILTER
BOSCH REACTOR
CO_2 AND N_2 FLOW CONTROL
CO_2 ACCUMULATOR
SILICA GEL
SILICA GEL
CATALYTIC BURNER
SPACE RADIATOR
LIQUID COOLED ELECTRONICS EQUIPMENT
CABIN AIR HEAT EXCHANGER
AIR COOLED ELECTRICAL EQUIPMENT
FECES DRYER
FILTER
CRYOGENIC OXYGEN
CRYOGENIC NITROGEN
4

weight and power limitations. The reliability of such systems is being seriously reviewed with regard to their application to space. The use of bacteria has more recently received serious consideration for biological systems application. Hydrogenomonas bacteria show promise for such biological applications.

As discussed in this paper, there are many workable concepts for water and atmosphere generation. The recycling or generation of food is a problem which is not as readily amen~~d~~able to solution however. Concepts for biological and physical-chemical synthesis of food are being investigated.

The solution of the problem of feeding in space for long duration will not only benefit man in space but in all probability the technology developed will be of even greater use to him on earth.

[redacted]

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